REPORT NO.T 2/78

12

INSULATING EFFECTIVENESS OF METALLIZED REFLECTIVE LAYERS IN COLD WEATHER CLOTHING SYSTEMS

U S ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE
Natick, Massachusetts

APRIL 1978

UNITED STATES ARMY
MEDICAL RESEARCH & DEVELOPMENT COMMAND

7

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

DISPOSITION INSTRUCTIONS

Destroy this report when no longer needed.
Do not return to the originator.

UNCLAS

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER T 2/78	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) Insulating Effectiveness of Metallized Reflective Layers in Cold Weather Clothing Systems		5. TYPE OF REPORT & PERIOD COVERED (9) Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) John R. Breckenridge		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Research Institute of Environmental Medicine, Natick, MA 01760		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS (16) 3E762777A845
11. CONTROLLING OFFICE NAME AND ADDRESS Same as 9. above		12. REPORT DATE (11) April 1978
		13. NUMBER OF PAGES 38
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) (12) 43 p.		15. SECURITY CLASS. (of this report) UNCLAS
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

(14) USARIEM-T-2/78

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Thermal radiation; clothing insulation; reflective clothing layers; metallized fabrics.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A physical analysis based on the laws of radiant energy transfer has been employed to indicate conditions under which metallized, reflective layers in fabric systems would be most likely to improve their insulating properties. This analysis suggests that such layers can be effective in reducing heat loss by radiation exchange through open-structured materials such as polyester batting, but have little potential when used in systems of densely-packed fibers or foam insulation, where radiation exchange is not a major factor. These indica-

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLAS 040 850

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

tions were verified by insulation measurements, made on a guard ring flat plate apparatus, on a variety of polyester batting systems containing reflective layers of aluminum foil, metallized plastic films, or metallic foils bonded to cloth under pressure (which fragmented the foil and made the reflective vapor permeable). Maximal effectiveness of reflectives was found when the systems were uncompressed, and had relatively thin batting layers with a metallic face next to each batting surface, i.e., two reflectives facing each other across every batt. In a system comprising two 68 g/m^2 (2 lz/yd^2) polyester batts, replacement of non-reflective layers between batts with four metallized films increased insulating value from 3.3 clo to 6.1 clo, an 85% improvement. However, substitution of film reflectives in systems containing 2 layers of 1.3 cm polyurethane foam increased insulation only 0.5 clo, or about 7% in this 7 clo system.

Failure to demonstrate similar benefits by adding reflective layers in the polyester liners of standard Arctic uniforms and mittens (10% maximal increase in insulating value) was explained by studying compressed batting systems on the flat plate. Stitching polyester batting systems containing reflectives into 10 cm rows and squares virtually eliminated all benefits of reflective layers. It was shown that, in reality, uncompressed batting provided only about 70% as much insulation as conventional moderately dense fabrics, which allow little radiant heat loss; reflectives simply minimized these losses in batting and made its thermal insulation per unit thickness almost the same (within 10%) as for denser fabrics. Compressing the batting made it more dense, and reduced both the radiant losses and the benefits possible with reflective layers. Under moderate to heavy pressure, batting used with reflectives provided 1.8 clo of insulation per cm thickness, only 16% higher than the 1.6 clo/cm found with most moderately dense textiles (without reflectives). Corrugated netting spacers placed next to the batting to reduce compression from stitching did not improve the clo/cm with reflectives but showed promise by minimizing the reduction in thickness and consequent loss of insulation under pressure.

Approved for public release;
distribution unlimited

AD ________________

TECHNICAL REPORT
NO. T 2/78

INSULATING EFFECTIVENESS OF METALLIZED REFLECTIVE LAYERS IN COLD WEATHER CLOTHING SYSTEMS

by

JOHN R. BRECKENRIDGE

April 1978

US ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE
Natick, Massachusetts 01760

Foreword

The concept of using reflective surfaces within the layers of cold weather clothing ensembles to improve their insulating effectiveness has had considerable appeal since the early 1940's. A certain fraction of the heat transfer through clothing occurs because of thermal radiation exchange between layers at different temperature, the amount depending on such factors as fabric porosity, weave, and spacing between layers. Reflective layers which emit and absorb this radiation poorly can, in theory, reduce radiant losses and provide increased insulation. Much of the early pioneering work was done by Prof. Alan C. Burton of Canada in connection with protection of military personnel against the cold. Investigations were also pursued by the Climatic Research Laboratory, Office of the Quartermaster General. Work was terminated because little benefit of reflectives in actual clothing could be demonstrated, despite encouraging laboratory findings. The subject was reopened in the 1950's by a commercial textile manufacturer, who employed direct vacuum deposition of aluminum on fabrics. No tangible benefits could be shown for these products when used in military clothing, although they are still being marketed for use in women's apparel, primarily because of their aesthetic appeal.

Interest in application of reflectives in military cold weather clothing was revived in 1968, despite past failures, primarily because low density polyester battings, which obviously allowed considerable radiation exchange, had replaced the heavier, more dense materials previously employed in garment liners, mittens, etc. It was reasoned at that time that, since the substitution of polyester battings had apparently not had an adverse effect on cold weather clothing protection, use of reflectives to minimize radiant exchange in the batting should produce important increases in insulating value. This Institute at that time initiated studies, using electrically heated insulation measuring apparatus such as a guard ring flat plate and copper manikin, to establish the design requirements for maximal benefits from reflectives. Initially, work was concerned with placement of reflective layers for maximal effect and development, in collaboration with USANARADCOM clothing personnel, of a vapor-permeable reflective. Later, after repeated failures to obtain important insulation improvement in clothing by including reflectives, the investigation was redirected toward explaining the causes of failure and suggesting remedial action. The results of this latter phase of the work have important implications which should be considered in any future proposal to employ reflectives in military clothing or personal equipment for cold weather applications.

PRECEDING PAGE BLANK

Abstract

A physical analysis based on the laws of radiant energy transfer has been employed to indicate conditions under which metallized, reflective layers in fabric systems would be most likely to improve their insulating properties. This analysis suggests that such layers can be effective in reducing heat loss by radiation exchange through open-structured materials such as polyester batting, but have little potential when used in systems of densely-packed fibers or foam insulation, where radiation exchange is not a major factor. These indications were verified by insulation measurements, made on a guard ring flat plate apparatus, on a variety of polyester batting systems containing reflective layers of aluminum foil, metallized plastic films, or metallic foils bonded to cloth under pressure (which fragmented the foil and made the reflective vapor permeable). Maximal effectiveness of reflectives was found when the systems were uncompressed, and had relatively thin batting layers with a metallic face next to each batting surface, i.e., two reflectives facing each other across every batt. In a system comprising two 68 g/m^2 ($2\ oz/yd^2$) polyester batts, replacement of non-reflective layers between batts with four metallized films increased insulating value from 3.3 clo to 6.1 clo, an 85% improvement. However, substitution of film reflectives in systems containing 2 layers of 1.3 cm polyurethane foam increased insulation only 0.5 clo, or about 7% in this 7 clo system.

Failure to demonstrate similar benefits by adding reflective layers in the polyester liners of standard Arctic uniforms and mittens (10% maximal increase in insulating value) was explained by studying compressed batting systems on the flat plate. Stitching polyester batting systems containing reflectives into 10 cm rows and squares virtually eliminated all benefits of reflective layers. It was shown that, in reality, uncompressed batting provided only about 70% as much insulation as conventional moderately dense fabrics, which allow little radiant heat loss; reflectives simply minimized these losses in batting and made its thermal insulation per unit thickness almost the same (within 10%) as for denser fabrics. Compressing the batting made it more dense, and reduced both the radiant losses and the benefits possible with reflective layers. Under moderate to heavy pressure, batting used with reflectives provided 1.8 clo of insulation per cm thickness, only 16% higher than the 1.6 clo/cm found with most moderately dense textiles (without reflectives). Corrugated netting spacers placed next to the batting to reduce compression from stitching did not improve the clo/cm with reflectives but showed promise by minimizing the reduction in thickness and consequent loss of insulation under pressure.

Introduction

The concept of using reflective metallized layers in cold weather clothing to reduce the heat loss from radiation exchange has had considerable appeal since the early 1940's. Burton (3) in 1943 found that metallized surfaces facing each other across an air space reduced long-wave (i.e. thermal) radiation effects by up to 42%. Later, U. S. Army research on air layers (14) showed even greater effects of reflective layers, with an 80% increase in insulation value. Fourt (9) found that two metal layers facing into an open knit fabric were also highly beneficial. On the other hand, Burton (3,4,12) found only a 15% improvement with reflectives facing a space filled with kapok or packed fibers. He also observed (3) that the reflecting power of a fabric depended on the particle size of the metal used to coat it; reflecting power ranged from 78% for 250 micron particles to only 18% when the mean particle size was 1 micron. This explains why certain commercial fabrics metallized by vacuum deposition have failed to show any promise for reducing radiation transfer through clothing (8).

Until recently, attempts to show beneficial effects from reflective layers in actual cold weather clothing or sleeping gear have met with little success; the insulation gains derived did not justify further effort, and the approach was virtually abandoned between 1955 and the late 1960's. However, two events have since dictated reassessment of the potential for metallized surfaces, namely (a) development by several manufacturers of highly reflective films and fabrics, including a reflective blanket which has been publicly accepted, and (b) a change in the lining materials in U.S. cold weather garments, from heavy, dense insulating fabrics to very low density polyester battings. The latter development greatly increases the potential importance of metallized layers since, with reduced fiber density, radiant transfer plays a much more important role (9). Studies, extending over a 6-year period, were therefore conducted to evaluate various manufactured reflectives, reveal the configurations under which optimal benefits might be expected, and establish methods of incorporating these metallized surfaces into practical clothing items to obtain significant improvements in insulation capabilities.

The purpose of this report is to summarize the results of these studies and, by defining the requirements for successful application of reflective layers in a clothing system, provide a basis for designing clothing with significantly improved insulating characteristics. The analysis of radiation transfer, and the role of reflective layers in reducing it, should help the clothing designer avoid pitfalls which, in the past, have prevented the realization of the maximal potential of radiation barriers in clothing and other protective items used by the soldier. This contribution is especially vital in view of the many attempts to employ reflectives, each of which has resulted in almost complete failure to achieve meaningful improvement in protection.

Theoretical Considerations

In the absence of wind, or air currents set up by body motion, sensible heat transfer (i.e. that associated with a temperature difference) through a moderately dense fabric occurs mainly by conduction through the layer of air trapped by the fibers (10,11) and by thermal convection set up by the temperature gradient across the fabric. The conduction component is a function of the thermal conductivity of

air, while the convection component is related to the density (buoyancy) differences in the trapped air layer (18,23). Burton (4) has noted that fiber conduction is not a major avenue for heat loss, except in very dense fabrics, since the fiber cross-sectional area in a given plane is only a small fraction of the total area; indeed, garments of comparable thickness of steel wool provide only about 12% less insulation than those of wool. As one may deduce from an analysis of the conductive - convective processes involved, the insulating values of moderately dense fabrics are reasonably independent of density and type of fiber employed. Experimental measurements on flat, single and multiple fabric systems consistently indicate insulating values in the vicinity (within $\pm$ 15%) of 4 clo (13) per inch (1.6 clo per cm) of thickness (5,11). Most of the variation can be traced to differences in fiber orientation (slightly lower values with the fibers perpendicular to the heat flow than when they are parallel) and, to some small degree, to variations in fiber density. It does not appear that increased density reduces thermal convection; insulation value generally falls as density increases beyond a certain point while reduced convection would lower heat loss, i.e. raise insulation.

Where the textile fabric has a low fiber density, as in polyester batting, another avenue of heat transfer, namely radiant heat exchange, becomes important Low density does not markedly reduce the ability of the fibers to immobilize air if there are no external pressures from wind, etc. However, the probability is increased that radiation emitted by an outside source (such as an adjacent layer) or from one of the fibers will travel a considerable distance before it is intercepted and absorbed by another fiber or surface at a different temperature. The net result is a transfer of heat from one point to the other. This potential for radiant transfer in a low density batting is readily apparent if one holds the batting up to a light. Many free paths for transmission of light, i.e. visible radiation, through the material may be seen; these paths are also available to the invisible thermal radiation emitted by any source above absolute zero temperature. Because of this additional mode of heat transfer, it is reasonable to expect that low density battings in an uncompressed state are less effective as insulators than moderate density fabrics; i.e., they may provide considerably less than 4 clo of insulation per inch thickness. This reduction in effectiveness has, strangely, not been demonstrated in comparing cold weather clothing ensembles and handwear incorporating batting liners with other systems employing more dense lining materials. For example, the insulation of the current standard U.S. Army Arctic uniform, which has polyester batting parka and trouser liners, measures 4.3 clo on a standing copper manikin in calm ($0.3\ m \cdot s^{-1}$) air, a value which is almost identical with that obtained on the earlier standard ensemble, which employed relatively dense liners at least as thick as the current liners. Of course, the batting liners are stitched together, and the polyester fibers may be compressed in the process, producing a denser material with less potential for radiant heat transfer. It should also be noted that much of the insulating value of an ensemble in "still" air is provided by the air layers between adjacent garments. We have, in fact, demonstrated that substitution of a thin fabric for a liner in an Arctic ensemble has practically no effect on the static insulating value measured with the copper manikin (2).

Radiation heat transfer between fabric layers

The principles of radiation heat transfer in a fabric can best be understood by

considering the idealized situation in which two infinite parallel planes at temperatures T_1 and T_2, respectively, are separated by a finite distance. It will be assumed, initially, that these planes are true blackbodies; i.e., that they absorb all radiation incident upon them. A blackbody is also a perfect emitter of radiation, with emissive power E_b, as defined by the Stefan-Boltzmann law (19):

$$E_b = \sigma T^4 \qquad \text{Equation 1}$$

where E_b = emissive power of a blackbody, $W \cdot m^{-2}$

σ = Stefan-Boltzmann constant, $5.67 \times 10^{-8}\ W \cdot m^{-2} \cdot T^{-4}$

T = absolute temperature, degrees Kelvin

Since each plane absorbs all the radiation emitted by the other, the net radiation transfer from plane 1 to plane 2 is:

$$R_{net} = E_{b_1} - E_{b_2} = \sigma (T_1^4 - T_2^4) \qquad \text{Equation 2}$$

where R_{net} is the net exchange in $W \cdot m^{-2}$.

A true blackbody rarely occurs in nature although it is closely approximated under certain conditions. It is not necessarily black in color, but is simply one which obeys Equation 1 for the spectrum of radiation being considered. For long-wave thermal radiation (wavelengths between 10^{-5} and 10^{-6} meters for exchanges between man and his environment), a surface coated with lampblack is almost a perfect blackbody. Human skin, flat paint of any color, and most textiles are also almost "black" at these wavelengths (17).

Departure of a surface from ideal blackbody characteristics reduces the emissive power, and the percentage of incident radiation which is absorbed, by a common factor called the emissivity ε. Emissive power, E for a non-blackbody source, is accordingly:

$$E = \varepsilon \sigma T^4 \qquad \text{Equation 1(a)}$$

The value of emissivity ε may range from 0, for a perfect reflector, to 1 for an ideal blackbody.

In the case of radiant heat transfer between fabric layers, where neither of the parallel planes is a blackbody, the radiant exchange will be reduced since neither plane emits maximally for its temperature nor absorbs all the radiation it receives from the other plane. To illustrate, the radiation absorbed by plane 2 is $\varepsilon_1 \sigma T_1^4$ (i.e. that emitted by plane 1) times ε_2. The radiation which is not absorbed, $(1 - \varepsilon_2)(\varepsilon_1 \sigma T_1^4)$, is reflected back toward plane 1. An analysis of this case produces the relatively simple expression for net radiant transfer:

$$R_{net} = \frac{\sigma (T_1^4 - T_2^4)}{1/\varepsilon_1 + 1/\varepsilon_2 - 1} \qquad \text{Equation 3}$$

For two planes with emissivities of 0.9 (i.e. 90% "black") their "combined emissivity" ε_c is 0.82, i.e.,

$$\varepsilon_c = \frac{1}{\frac{1}{0.9} + \frac{1}{0.9} - 1} \qquad \text{Equation 3(a)}$$

$$= \frac{1}{1.2222} = 0.82$$

and the net radiant exchange R_{net} is 82% of that for blackbody planes (where $\varepsilon_c = 1$). If the planes are of polished metal with emissivities of 0.05, the net exchange is only 2.6% (0.026) of the transfer with blackbodies. From this, it may be seen that radiant exchange across an air layer between two layers of fabric may be greatly reduced if their surfaces have low emissivity, i.e. are "reflective". The same is true if the outer surface of a fabric system is metallized to make it reflective. It should be noted that in this case ε_2, the emissivity of the surroundings, will probably be near 0.9; this will increase the "combined emissivity" for the surface - surroundings system, i.e., the reciprocal of the denominator in Equation 3, to perhaps 0.05.

Radiation heat transfer within a single fabric layer

In a textile fabric, or batting, the space between the two surfaces of a single fabric layer is subdivided by many thin, fiber "planes". The effect of such subdivision on radiant heat transfer may be shown with our parallel plane model by interposing a third plane to divide the original spacing into two equal parts. If the emissivities of all the planes are equal, the absolute temperature of the middle plane (T_3) will be governed by the relationship:

$$T_3^4 = 1/2(T_1^4 + T_2^4) \qquad \text{Equation 4}$$

and, since the net radiant transfers from plane 1 to plane 3 and from plane 3 to plane 2 must be equal, the transfer between the original planes 1 to 2, is:

$$R_{net} = \frac{1/2\sigma(T_1^4 - T_2^4)}{1/\varepsilon_1 + 1/\varepsilon_2 - 1} \qquad \text{Equation 3(b)}$$

which is half that given by Equation 3 (20). If an additional plane is inserted between planes 1 and 3 and also one between 3 and 2, the net exchange is reduced to one-quarter of the original, and still further additions produce further reductions. Thus, it is evident that the more densely the fibers in a fabric are packed, the lower the net radiant heat transfer across the fabric layer will be, for a given temperature gradient. In a dense fabric, there are so many "planes" of fibers, each at a temperature only slightly different from the adjacent "planes", that R_{net} across the fabric layer must be extremely small. Therefore, low emissivity fiber coatings, or highly reflective surfaces in contact with the fabric, can obviously have little or no effect since there is practically no radiant heat transfer to block. Of course, a reflective film not in direct contact with the fabric will still cause some reduction in heat transfer since a finite, measurable temperature difference exists across the air space between the film surface and the fabric surface; their emissivities therefore affect the amount of radiation transfer which results.

In materials where fiber density is extremely low, such as polyester battings,

the effective distance, and the temperature difference between any two fiber "planes", is relatively large. Fibers in one "plane" may exchange radiation with fibers in other distant "planes", or even with surfaces completely outside the batting. Reflective surfaces facing the batting obviously can be effective in reducing radiant heat exchange between internal fibers and outside surfaces, and also for reflecting radiation which originates outside the batting and passes completely through it without being intercepted by the relatively few fibers. However, reflective coatings on the fibers themselves may provide only limited benefits, since radiation incident on a fiber would be scattered in all directions rather than being reflected back toward the emitting source. Some of this scattering would be in a forward direction, i.e., a continuation of the original radiation path; other rays would experience multiple reflections until a) their energy was all absorbed by the fibers, or b) they escaped from the batting. The net result would be no better, and possibly worse, than with non-reflective fibers. Pratt (22) has observed for solar radiation, that penetration of pile materials was greater when the fibers were light-colored, and thus reflected the radiation, than when they were dark and immediately absorbed most of the radiation. Because incoming solar radiation was reflected deeper into the pile by the light colored fibers, net solar heating was actually higher than with the dark fibers, even though the latter absorbed more of the incident radiation.

Materials and Methods

Studies to assess the insulating effects of a variety of metallized reflective layers in a fabric system were conducted primarily on an electrically-heated, guard ring flat plate (7,15,16,21) located in a temperature and humidity controlled cabinet. A few of the more promising systems identified on the flat plate were subsequently duplicated in handwear and footwear items, or in the liners of experimental cold weather ensembles to assess whether the suggested benefits could be provided in actual clothing; these items were measured on a 21-section copper hand, a 12-section copper foot, or a single-section copper manikin, respectively. The metallized layers employed included thin-film plastic layers with metallic coatings deposited on one or both surfaces, conventional aluminum foils, and special metallized fabrics produced by bonding a thin metallic foil to the fabric under such heavy pressure that the foil was ruptured and forced into the fabric interstices. This process provided an extensive metallic coating on the fabric, while still not destroying its vapor permeability.

In addition to one or more reflective layers, the fabric systems contained one, and sometimes two, layers of 68 gm/m^2 (2 oz/yd^2) staple-fiber polyester batting, or two layers of 136 gm/m^2 (4 oz/yd^2) continuous filament polyester batting. Some combinations were also made up using one or two layers of polyurethane foam, rather than the less dense battings, to check on the benefits of reflective layers with unusually dense materials. The reflectives in all these combinations were placed in various positions, and orientations, with respect to the batting or foam layers; i.e., beneath, between, and outside these layers, with the metallized surface(s) facing both up and down in the systems. Other components, such as thin layers at the system surface, and various textiles between the plate and the bottom batting layer, were employed in some cases. Finally, control systems, with non-metallized layers substituted for the reflectives, were utilized to establish the magnitude of insulation improvement for a given placement and orientation of reflective layers.

Flat Plate Studies

In the flat plate studies, the plate was always used in a horizontal position with the layers of the system resting upon it. These studies can be divided into three categories: 1) analysis of uncompressed systems; 2) measurements on prepared systems held together either by rows of stitches spaced 10 cm (4") apart or by lengthwise plus crosswise stitching which divided the sample into 10 cm x 10 cm squares; 3) measurements on compressed, unstitched systems. In the first series, the layers in the system were under no pressure other than that due to their own weight. A light metal frame, 2.5 cm in width, was used to weigh down the fabrics at the outside edge of the guard to minimize air penetration and lateral flow through the system, but this compression at the very edge of the sample did not alter the thickness of the system over the plate test section, a 25 cm x 25 cm (10" x 10") area in the center of the 53 cm x 53 cm (21" x 21") plate. Studies with the edges of several systems also sealed with tape established that the metal frame was effective in preventing edge effects; at least, the results with the frame alone were no different than those with the edges taped and the frame in place. In the second series, the stitched 53 cm x 53 cm sample was simply placed on the plate, and the metal frame set in place Its weight was usually sufficient to close gaps between the sample and the plate; if not, the gaps were plugged with small pieces of polyester batting inserted at the outside edge of the guard. The third series, designed to study the effectiveness of reflective layers with higher density polyester battings, was conducted by progressively increasing the weight on top of the system to compress the batting. Initially systems which included two layers of 136 g/m^2 continuous filament polyester were studied. Uniform loading of the sample was obtained by covering it with a square of hardware cloth (screening) with wires on 1.3 cm (½") centers and then by a rigid 25 cm x 30 cm (14" x 16") flat cooling rack such as used in the kitchen for cooling cakes, etc. Where more than the weight of the hardware cloth and rack was desired, equal weights were placed at the four corners of the rack. Using this weighting system, the thickness of the sample over the test section was reduced to approximately 1/5 of its no-load value, corresponding to a density increase of about five-fold in the polyester batts. Subsequently, measurements were also made on weighted systems which included semi-rigid corrugated netting spacers, in combination with 68 g/m^2 (2 oz/yd^2) short staple polyester batting, to assess the effectiveness of the spacers in preventing compression. These measurements were undertaken after it became apparent that the benefits of reflective layers were greatly reduced when they were used with batting compressed either by weight or stitching used to hold a system together.

The procedures followed in the flat plate measurements were standard for this device, which is shown schematically in Figure 1. It consists of a 25 cm x 25 cm (10" x 10") test section, on which calculations are based, surrounded by a 53 cm x 53 cm (21" x 21") guard frame in the same horizontal plane. These two plates, of blackened 3.2 mm (1/8") copper, are supported on a wood frame approximately 3.8 cm (1½") above a 53 cm x 53 cm heated bottom plate. A uniform grid of #30 AWG constantan wire, cemented to the inner face of each plate, is supplied with power from a proportional power controller connected to a thermistor sensor imbedded in the plate. This arrangement permits controlled heating of each plate to a desired temperature, with a maximum deviation from the set point of less than 0.05°C over extended periods of time. Each plate section is also fitted with a number of imbedded #30 AWG thermocouples connected in parallel (5 in the test section, 8 in

the guard, and 6 in the bottom) to obtain a representative mean temperature for each. The test section is also equipped with two surface thermocouples in parallel which indicate any discrepancy between the average internal test section temperature and its surface temperature; this difference is usually insignificant, except when the test section is bare or covered only by very thin fabrics. Two additional thermocouples, one on the underside of the test section and the other directly beneath it on the top side of the bottom plate, are connected in series to indicate any difference in temperature between the test and bottom inner surfaces; during a measurement, the temperatures of these two surfaces are equalized (i.e., adjusted so that the output of the series couples is zero) to insure that the bottom section is not supplying heat to the test section or vice versa. The chances of this occurring are also minimized by packing the space between the topside (guard and test) and the bottom plates with polyester batting.

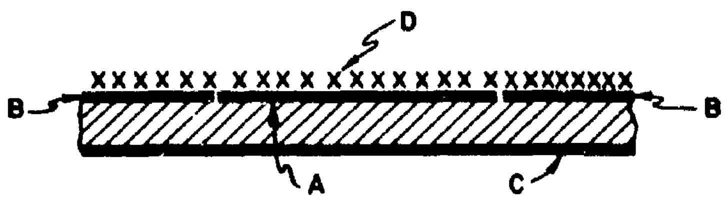


Figure 1: Schematic diagram (side view) of Guard Ring Flat Plate. Test section A is surrounded by guard section B. Bottom section C prevents downward heat loss from test section. Fabric under test is designated by D.

In operation, the test section is adjusted to about 33°C (approximating human mean skin temperature) and the guard temperature to within 0.05°C of the test section. This balance prevents lateral heat exchanges between the test and guard section coverings and, with the bottom section set as described above, permits the assumption that, at equilibrium, the power required by the test section is exactly equal to the heat transferred from the test section to the environment. Thus, the total insulation (I_{tot}), which includes that of the fabric system (I_{int}) plus its overlying air layer (I_a), is:

$$I_{int} + I_a = I_{tot} = \frac{6.46(\bar{T}_s - T_a)(A)}{P} \qquad \text{Equation 5}$$

where
I_{tot} = insulation of system plus air layer, clo units
$\bar{T}_s$ average temperature of test section, °C
T_a = air temperature, °C
A - test section area, m^2

P - heating power to test section, W.

During measurements, the flat plate was positioned in the center of a 1.0 cubic meter temperature/humidity controlled cabinet; it rested on a 2.5 cm thick layer of dense foam material (used to minimize heat losses from the bottom section) supported on a tubular frame, which placed the test section approximately 46 cm (18") above the cabinet floor. Air movement across the surface of the plate was approximately 0.7 $m \cdot s^{-1}$, and chamber temperature was set between 5°C and 25°C, depending on the thickness of the sample being studied. This temperature adjustment was made according to the arbitrary guideline that power input to the test section be between 2 and 4 W; the thickest insulation systems required a 5°C ambient temperature while thin (<5 mm) systems used the 25°C temperature. After the test cabinet had stabilized, the temperatures of the three sections were set as specified above, and the entire system equilibrated for at least 3 hours. Three to four sets of 15-minute measurements were then made, at approximately 45-minute intervals, and an average insulating value was calculated from the values for these individual runs. During each run, the several plate and cabinet temperatures were periodically monitored using a precision, manually balanced potentiometer, which was connected to the thermocouples through an ice reference bath. The plate temperatures were quite steady, but chamber air temperature varied by ± 0.1°C and had to be followed through several heating and cooling cycles before arriving at a representative average value for T_a. Power to the test section was continuously recorded, using a millivolt range strip chart recorder connected to the output of a thermal wattmeter which was placed in the circuit between the test section heater and its temperature controller. This controller was somewhat affected by voltage and frequency transients on the power mains, and the recording was not a steady straight line. The possibility of error in estimating the average power level on the chart was estimated as 0.05 W, or about 2% when the power level was near the 2 W lower limit. Increased accuracy in measuring power could, in theory, have been obtained by operating the chamber at very cold temperatures for all runs (to require high power inputs to the test section) but, with the resulting high heat loss, the difference between the imbedded and surface couples became unacceptable (>0.1°C) and there was less assurance that the test section was at a uniform temperature laterally. This of course would affect the adequacy of guarding by the guard plate, which would also show lateral variations in temperature.

In making the calculations, the temperature $\bar{T}_s$ was taken as that measured at the surface of the test section rather than that indicated by the average of the imbedded thermocouples. The differences in all experiments were generally quite small (<0.05°C) and use of either temperature would have been acceptable from an error standpoint, since the gradient ($\bar{T}_s - \bar{T}_a$) was never less than 8°C.

Sample thickness was measured only in the third series, involving compressed batting systems; omission of such measurements in the first two phases was unfortunate since thickness data would have helped in interpreting and analyzing the results. In the compression studies, thickness measurements were made, in situ, by measuring the elevation of the upper surface of a system relative to that of the bare plate. This was done using a small plumb bob attached to a line which passed over pulleys on the chamber ceiling and then to a connection on a vertical vernier reading to 0.1 mm. Readings were taken by slowly lowering the plumb bob, as it wobbled to and fro, until the surface was just contacted. Several readings at

the sample surface and at the surface of the bare plate were made during each determination. With this arrangement, it was possible to obtain only one measurement of thickness, at the center of the test section, on each sample. Although there were undoubtedly thickness variations over the sample, these variations could not be shown without disturbing the sample, moving the plate, or using multiple plumb bobs. Every precaution was taken to obtain a plane surface without wrinkles or depressions, when the sample was placed on the plate. Thickness values are considered as representative, within $\pm$ 1 mm, of the average over the entire test section.

Studies with other devices

Several of the more promising insulation systems were duplicated in actual clothing items to determine how well the effect of a particular design change, as observed with the plate, correlated with the effect on insulation value under the less-than-ideal conditions represented by practical clothing. Early studies of clothing items incorporating reflective layers were, in fact, the stimulus for the extensive flat plate evaluations of stitching and compression effects since stitched items failed to show the benefits which were indicated by the plate studies on uncompressed, unstitched systems.

The general approach followed in evaluating the clothing items, using the sectional copper hand, sectional copper foot, or single-section copper man, was similar to that for the plate; i.e., heat loss under stable equilibium conditions was determined by power input measurement, and converted to insulating value using Equation 5. In measurements with the 21-section hand and 12-section foot, all sections were brought to the same temperature by adjusting rheostats in the heating circuits. Each section was thus "guarded" by the sections surrounding it, minimizing lateral flow above adjacent sections. It could then be assumed that heat to a given section was lost through the fabrics covering that section; this permitted the calculation of sectional insulating values, as well as an overall insulating value. Measurements on the sectional hand and foot were made in a cabinet identical with that used for the flat plate work. The device was positioned on a metal grille, at approximately the same height above the chamber floor as the flat plate, so that air movement over the experimental item was comparable to that over the plate. Studies on other clothing items were done in a large environmental chamber on a life-size, standing copper manikin; the manikin used was a single-circuit variety with 21 thermocouples distributed over the surface, and contained automatic temperature control sensors like the plate sections. Methods of control, and power measurements were the same as for the plate test section. Surface and air temperatures were measured with a 24-point strip chart recorder. The environmental conditions for most runs were 27°C air temperature with 50% relative humidity, and 0.3 $m \cdot s^{-1}$ air movement. In addition, a few runs on experimental sleeping bags incorporating reflective layers were made at an air temperature of -7°C with the manikin supine.

Results and Discussion

Flat Plate Studies. To simplify the presentation and analysis of the results obtained on the guard ring flat plate, which are rather voluminous, they have been grouped into categories which best demonstrate general rules and principles for the

TABLE I

STAPLE-FIBER 68 g/m^2 (2oz/yd^2) BATTS WITH REFLECTIVE MYLAR FILM METALLIZED ON ONE FACE

SYSTEM	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
PLASTIC ON COTTON	—	—	—	—	—	—	—	—	—
REFLECTIVE LAYER			⊥		⊤	⊥	⊥	⊤	⊤
POLYESTER BATT	□	□	□	□	□	□	□	□	□
REFLECTIVE LAYER		⊤		⊥		⊤	⊥	⊤	⊥
T-SHIRT FABRIC	—	—	—	—	—	—	—	—	—
TOTAL INSULATION, clo	1.82	2.10	2.11	2.30	2.32	2.46	2.98	2.63	2.82

SYSTEM	(j)	(k)	(l)	(m)	(n)	(o)	(p)	(q)	(r)
PLASTIC ON COTTON	—	—	—	—	—	—	—	—	—
REFLECTIVE LAYER			⊥		⊥			⊤	⊥
POLYESTER BATT	□	□	□	□	□	□	□	□	□
REFLECTIVE LAYER		—*	⊥	⊤	⊤	⊥	⊥	⊤	
POLYESTER BATT	□	□	□	□	□	□	□	□	□
REFLECTIVE LAYER		—*		⊤		⊤	⊥		⊥
T-SHIRT FABRIC	—	—	—	—	—	—	—	—	—
TOTAL INSULATION, clo	2.77	2.94	4.01	4.19	4.16	4.20	4.27	4.45	3.72

*CLEAR PLASTIC LAYER

application of reflective layers. In analyzing these results, particular emphasis will be placed on two considerations: 1) the level of radiant heat transfer to be expected in materials comprising a given fabric system; and 2) whether or not the positions and orientations of reflective layers added to the system were best for reducing this radiant transfer.

1. Systems employing polyester batting and metallized films.

Basic principles for employing reflective layers with low-density battings were obtained using systems of one or two layers of 68 gm/m^2 short staple, polyester fiber between a T-shirt fabric and an impermeable outer layer with a cotton backing. These systems, which are shown schematically in Table I along with their insulation values, also included one to two thin films, of either clear plastic or mylar metallized on one side; the other side of the mylar was covered with an opaque, blue coating. In this table and those which follow, the position of a metallized surface is indicated by the direction of the arrow; i.e., an upward-pointing arrow indicates that the top face is metallized, etc. The fabric systems were placed lightly on the plate and measured under no compression other than that due to the fabric weight per se.

With one layer of 68 g/m^2 polyester (Table I a through i), insulation values range from 1.82 clo with no films, to 2.82 clo with two reflective films. Combinations b and c, with the metal face away from the batting, show an insulation increase over the control (a) of 0.28 - 0.29 clo; some of this increase (perhaps ~ 0.1 clo) results from the extra layer in b and c (this effect is evident in comparing combination j with k, which has two clear film layers added). The metal film serves little purpose in b or c, since it lies directly against a moderately dense, albeit thin, cotton layer. Consequently, there is little radiation to eliminate. Turning the metal face toward the batting (combinations d and e) has almost twice the effect, adding 0.2 clo to make a total of 2.3 clo, since the batting is thicker and thus has a much larger temperature gradient across it. Using two metallized films, both facing away from the batting (f), provides a further increase (to 2.46 clo) but the improvement is due to an extra layer. Facing both reflectives either up or down (combinations g and h) results in about 0.15 clo additional increase; in these combinations, one metal surface is facing the batting, and the other lying against a cotton layer, so that the benefits of the films are not maximal. When the film next to the T-shirting is reversed (i) so that the two metallized surfaces are facing each other across the batting, their combined emissivity (cf. Equation 3a) is minimal, and the maximum insulation, 2.82 clo, for these single-batting combinations is obtained.

In combinations b through e, and g and h, the insulation values appear to be unaffected by the orientation of the metal faces; i.e., whether they face the warmer plate or the cooler environment. This is reasonable to expect where only one metal surface is facing the batting, especially since the batt always had approximately the same temperature gradient across it.

With two layers of batting (combinations j through r) there is more potential for reflectives than with the thinner, one-layer system since the path lengths for radiation exchange without control or reflective films are longer. A total increase of almost 1.7 clo above that for a system with no films (j) was produced by placement of two reflective surfaces for maximal effect (system q). In combinations l through o, where there is only one metallic surface facing a batting, there is

over 1 clo insulation improvement in all cases (over that for control system k), compared to, at best, 0.8 clo improvement for g and h with one layer of batting. Finally, combinations p and q, in which a metal surface faces each batt, show a further increase of about 0.2 clo. This is not a tremendous improvement considering that two metal faces (instead of one in combinations l through o) are effectively employed. However, one surface next to each batt is virtually "black" so that radiant transfer is not reduced to a minimum with these arrangements. As will be shown, further reductions may be effected by making these "black" surfaces reflective, i.e., by using more than two reflective layers.

Actually, system k was not a true control for the two-batt systems and the indicated benefits of the eflective films are too high. Apparently the clear plastic layers were partially transparent to long-wave radiation, since substitution of opaque paper or cloth layers (in thick systems studied later) produced higher clo values. With a transparent plastic layer between batts, the path lengths for radiation exchange in system k would extend across the entire system, from the T-shirt layer to the outer cover; radiation heat loss would therefore be much greater than with subdividing, opaque, radiation barriers such as paper. Thus, the clo value for system k is too low (perhaps by 0.2 to 0.3 clo) for it to serve as a control for comparison with systems containing reflective layers, since the metallized mylar was opaque, or very nearly so, to long-wave radiation.

Discussion of the results for system r in Table I has been held until last to emphasize a rather important point. This system has two reflective faces, with the lower one facing the batting, but the insulation value is less than for any other two-batting system with two reflectives. The main reason for this low value is that the films are separated by two batting layers instead of one. In essence, these layers constitute one thick layer with a large temperature gradient across it. Thus, the potential for radiant exchange between distant fibers is high. The single reflective layer facing into the batting can reduce effects of radiation exchange between its metallized surface and the fibers, as well as effects of direct line-of-sight exchanges with the upper film, but cannot alter interfiber exchanges. Clearly, reflective layers are more effective where the batting layers are thin, and the path layers short, especially if each batting is faced with reflectives. Only two reflective layers can be used with one thick batt, but four could be used, to greater effect, with two batting layers which were only half as thick.

A summary of results for systems employing two layers of 68 g/m^2 batting and two to four films metallized on one side is given in Table II. Also included are values for aluminum foil reflective layers, a NASA film (the type used as a solar radiation shield over a malfunctioning Skylab orbiter), and the first of a series of vapor permeable reflectives formed by bonding a sheet of metal to a fabric under heavy pressure to cause fragmentation of the metal and force it into the fiber interstices. The NASA film was reflective on only one side since it had an opaque orange backing. The other films, although metallized on only one face, may have acted as double-faced films since they were not backed by opaque material. Data in the literature indicate that mylar or polyvinyl chloride films are partially transparent to long-wave radiation, so that metal deposited on one face can be "seen" by fabrics lying next to the uncoated face. Radiation from these fabrics would therefore be reflected by the underside of the metallic coating or, in effect, the film would act as though it had metal on both faces. Thus, the orientation of the metallic face on a one-sided film, i.e., whether or not it faced a batting layer, should be of little consequence. Some subsequent results support this "two-sided

TABLE II

SUMMARY OF RESULTS FOR VARIOUS REFLECTIVES WITH 68 g/m² (2 oz./yd.²) POLYESTER BATTS

	SYSTEMS											
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)
37 g/m²(1.1 oz./yd.²) NYLON	—	—	—	—	—	—	—	—	—	—	—	—
REFLECTIVE LAYER	—		⊤		⊥	⊤	⊤			⊤	⊥	⊤
POLYESTER BATT	□	□	□	□	□	□	□	□	□	□	□	□
REFLECTIVE LAYER	—	⊤	⊤	⊥			⊥	⊤	⊥⊤	⊤	⊥	⊥⊤
POLYESTER BATT	□	□	□	□	□	□	□	□	□	□	□	□
REFLECTIVE LAYER	—	⊤		⊥	⊤	⊥		⊥		⊤	⊥	⊥
37 g/m² (1.1 oz./yd.²) NYLON	—	—	—	—	—	—	—	—	—	—	—	—

TYPE OF REFLECTIVE LAYER	INSULATION VALUES (clo)											
¼ MIL POLYVINYL CHLORIDE FILM (ONE SIDE METALLIZED)	3.34	5.10	5.26	—	—	—	—	—	—	5.89	5.89	—
½ MIL POLYVINYL CHLORIDE FILM (ONE SIDE METALLIZED)	—	—	5.41	—	—	—	—	—	—	5.68	—	—
NASA REFLECTIVE (ONE SIDE METALLIZED, OTHER SIDE OPAQUE)	—	4.60	4.94	5.12	—	4.58	4.92	4.90	4.82	5.12	5.04	6.15
METAL-ON-CLOTH #1237	3.47	4.65	5.10	5.26	3.45	4.86	5.07	5.15	5.11	5.27	5.37	6.91
ALUMINUM FOIL	—	—	—	—	—	—	—	—	—	6.68	6.45	—

hypothesis".

Although not all combinations were measured with each of the films in Table II, it is apparent that their reflective characteristics were all similar, regardless of thickness or manufacturer, since each had about the same effect when used in a given layer system. The exception was the NASA reflective film with opaque backing, which produced lower insulating values. This film seemed as shiny as the others; however, it had only one reflective face while the others were, in effect, "two-sided". It is of course possible that the metallic coating on the NASA reflective was not as effective, i.e., had higher emissivity than the other coatings. However, the "two-sided hypothesis" seems to provide a better explanation for the differences since the results for the NASA reflective agree more closely with those for the backed reflective in Table I than with those for the unbacked films. For example, in Table II combination (b), the unbacked film increased insulation (over control) by 1.76 clo, versus 1.26 clo with NASA reflective and 1.25 clo with the backed reflective of Table I (m minum k). For the combinations like Table II(c), with two metal faces next to the batts, the increases are respectively 1.92 clo, 1.60 clo, and 1.51 clo (q minus k in Table I).

The superior insulating values with the aluminum foil reflective layers in systems j and k indicate that neither the metallized films nor the metal-on-cloth reflectives were optimally effective for reducing radiant energy exchange. Considering all factors, it would appear that the foil had lower emissivity (i.e., was a better reflector) than the thin metal deposit on the films; such a thin layer was apparently only partially reflective despite its shiny appearance. Carli (6) has in fact shown recently by mathematical analysis that although a very thin metallic layer ($< .01\ \mu$ thick) is a good reflector of visible radiation, a much thicker layer is required for the long wave, infrared radiation with which we are dealing in clothing heat exchange. The foil had two reflective faces, but so also did all the films, except the NASA, if our "two-sided" hypothesis is correct. In fact, values in Table III for films metallized on both faces are not greatly different from those for single-faced, unbacked films in Table II. There may be one other contributing factor, namely, that the unbacked films transmitted some long-wave radiation. As a result, the long paths between the two batts may not have been as completely eliminated as they were with the aluminum foil. These long paths were blocked when the NASA reflective was used; it had only one reflective face, while the foil had two, but the differences in insulation value (about 1.5 clo) could not possibly be due to this fact alone; it must therefore be concluded that the deposited metal layer on the film was not as effective as the solid foil.

The permeable, metal-on-cloth reflective (#1237) appears to be a satisfactory reflective substitute for a metallized film which, being vapor impermeable, is not suitable for most clothing applications. Clo values with this reflective are lower than with the translucent films but higher than with the NASA film which, like #1237, had only one reflective face. The metal layer was relatively thick, as with aluminum foil, but its reflective characteristics were inferior since the metallized surface was irregular and discontinuous (fragmented). It should be noted that #1237 reflective, one of the earliest versions of this type, was less effective than other metal-on-fabric types which were evaluated later.

Because it was truly one-sided and reasonably opaque, results with the #1237 reflective clarify certain principles regarding orientation of metal faces for maximal effect. These results (as presented in Table II) show very clearly that a reflective surface that does not face a batt has practically no effect; e.g., system

TABLE III

RESULTS FOR 68 g/m² (2 oz./yd.²) BATTING SYSTEMS WITH REFLECTIVE FILMS METALLIZED ON BOTH FACES

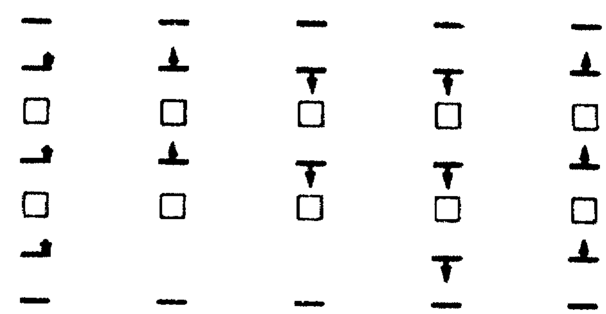
37 g/m²(1.1 oz./yd.²) NYLON	—	—	—	—
REFLECTIVE LAYER	↕		↕	↕
POLYESTER BATT	□	□	□	□
REFLECTIVE LAYER	↕	↕		↕
POLYESTER BATT	□	□	□	□
REFLECTIVE LAYER		↕	↕	↕
37 g/m² (1.1 oz./yd.²) NYLON	—	—	—	—

TYPE OF FILM	INSULATION VALUES (clo)			
¼ MIL POLYVINYLCHLORIDE	—	—	—	5.54
½ MIL POLYVINYLCHLORIDE	5.31	5.24	4.31	5.63
0.6 MIL POLYVINYLCHLORIDE	—	—	4.07	5.58

TABLE IV

RESULTS FOR 68 g/m² (2 oz./yd.²) BATTING SYSTEMS WITH NEEDLE-PUNCHED FILMS OR ALUMINUM FOIL WITH 1.3 cm (½ INCH) HOLES

37 g/m² (1.1 oz./yd.²) NYLON
REFLECTIVE LAYER
POLYESTER BATT
REFLECTIVE LAYER
POLYESTER BATT
REFLECTIVE LAYER
37 g/m² (1.1 oz./yd.²) NYLON



*CLEAR PLASTIC

TYPE OF REFLECTIVE	INSULATION VALUES (clo)				
½ MIL PVC WITH PIN HOLES (A*)	—	—	—	5.00	5.27
½ MIL PVC WITH PIN HOLES (B*)	—	—	—	5.23	5.83
GAUZE-BACKED ALUMINUM FOIL WITH 1.3 cm (½ INCH) HOLES	3.35	4.89	5.46	5.61	5.47
PLAIN ALUMINUM FOIL (FROM TABLE II)	—	—	—	6.68	6.45

*SAMPLES FROM TWO MANUFACTURERS.

TABLE V

EFFECTIVENESS OF REFLECTIVE FACE ON OUTSIDE OF BATTING SYSTEM (68 g/m² BATTS.)

SYSTEM	(a)	(b)	(c)	(d)
REFLECTIVE*		⊥	⊥	
POLYESTER BATT	□	□	□	□
REFLECTIVE*	⊥		⊥	⊥
POLYESTER BATT			□	□
REFLECTIVE*				⊥
T-SHIRT FABRIC	—	—	—	—
TOTAL INSULATION, clo	2.37	2.41	4.66	4.70

*½ MIL MYLAR FILM METALLIZED ON ONE FACE, OTHER FACE WITH OPAQUE BLUE BACKING.

(e), with two reflectives, has no better insulation than one with clear plastic (a), and only about 0.3 clo more than a system with no films (not illustrated). Reversing the two reflectives (f) adds 1.4 clo. Two reflectives facing batting have practically the same effect, regardless of their placement, as long as the two batts are isolated: systems c, d, g, h, i, j and k, with such configurations, all have insulation values in the narrow range from 5.07 to 5.37 clo. In j and k, the third reflective is incorrectly oriented and therefore its effect is practically nil.

Results for combinations utilizing double-faced film reflectives (Table III) require little comment, since the clo values are only slightly higher than for comparable systems in Table II using single-faced films (excepting the NASA reflective values). There seems to be little advantage in pursuing films metallized on both faces in clothing since, from all appearances, a single-faced film is equally as effective providing it does not have an opaque backing.

Before the bonded metal-on-fabric reflectives were developed all effective reflectives were impermeable. Therefore, several combinations using either perforated films or aluminum foil with 1.3 cm (½") diameter holes on a gauze backing were studied; the perforations and holes were intended to provide some vapor permeability. Results for these combinations are given in Table IV. Perforations in reflective films reduced effectiveness only slightly compared with the continuous-film values in Table II. However, the 1.3 cm (½") holes in aluminum foil had a marked effect, reducing insulation value by 1 clo below that of the continuous foil; nevertheless, these values with perforated foil were still almost as high as with unperforated metallized films (cf. Table II).

The effect of a reflective film directly exposed to the surroundings (i.e., on the surface with the metallized face outward) is shown by the results in Table V. Systems a and b, and systems c and d, have almost identical clo values, which indicates that an outer reflective has about the same effect as one within a polyester batting system, at least for the case where the metallized surface is facing outward toward a batting layer. This suggests that a reflective layer reduces the radiant exchange across a batting layer as much as it does across a free air space, i.e., from a batting surface to the surroundings. Perhaps this statement is an oversimplification, since a batting surface is undefined for radiant exchange; i.e., the radiation passing to the surroundings is only partly emitted from the exposed surface fibers while the rest may come from within the batting.

Efficacy of permeable reflectives.

A series of measurements was made to compare the effects of a variety of bonded metal-on-fabric reflectives made by the same process as #1237, discussed earlier. For proprietary reasons, none of these can be described or given the manufacturer's designation, except one prepared under contract for the U.S. Army Natick Research and Development Command (NARADCOM reflective), which was a 37 g/m^2 ripstop nylon with metal pressed into the surface. All of these reflectives were evaluated in systems containing 2 layers of 136 g/m^2 continuous filament batting, in place of the 68 g/m^2 short staple fiber batting used earlier. In addition, 204 g/m^2 cotton sateen layers were substituted for clear plastic in the control system for this series of measurements. Results of a series of measurements using the NARADCOM reflective in the most promising configurations are given in Table VI. In combination c, two reflectives separated by a double layer of batting increase insulation over the control (b) by 1.4 clo. An additional

TABLE VI

136 g/m² (4 oz./yd²) BATTINGS WITH BONDED METAL-ON-CLOTH REFLECTIVE
(37 g/m², 1.1 oz./yd² RIPSTOP NYLON NARADCOM REFLECTIVE)

SYSTEM	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
37 g/m²(1.1 oz./yd.²) NYLON	—	—	—	—	—	—	—	—
REFLECTIVE LAYER		—*	↓	↓	↓	↓	↓	↓
POLYESTER BATT	□	□	□	□	□	□	□	□
REFLECTIVE LAYER		—*		—	↓	↓	↑	↑↓
POLYESTER BATT	□	□	□	□	□	□	□	□
REFLECTIVE LAYER		—*	↑	↑	↓	↑	↑	↑
37 g/m² (1.1 oz./yd.²) NYLON	—	—	—	—	—	—	—	—
TOTAL INSULATION (clo)	5.48	5.94	7.38	7.58	7.88	8.60	8.82	9.96

*204 g/m² (6 oz./yd²) COTTON SATEEN LAYER .

0.2 clo is obtained simply by inserting a layer of sateen to subdivide the long paths through the two batts (d). In combination e, this layer is made reflective but the lower one is incorrectly oriented, (i.e., toward the plate) so that the net increase is only 0.3 clo. Reversing the lower reflective to face the batting has a marked effect, increasing insulation by 0.7 clo (f). The middle reflective is obviously quite vital since it provides a net insulation increase of over 1.2 clo (f vs c), primarily because of its reflective surface but also because of its subdividing effect. The orientation of this reflective seems unimportant (cf. f and g) but addition of a second reflective, facing in the opposite direction, in the middle produces an obvious added benefit of well over 1 clo (h). This approach (system h) in which reflective surfaces face one another across each batt, is obviously the optimal configuration. Higher insulation might be provided by reducing the batting thickness and compensating for this reduction by increasing the number of batts and reflective layers. Such a combination unfortunately might not be practical owing to the large number of layers.

Five additional bonded, metal-on-fabric reflectives employing cotton fabrics ranging in weight from 136 to 272 g/m^2 (4 to 8 oz/yd^2) were subsequently studied, using systems similar to f and h in Table VI (except that the inner and outer 37 g/m^2 (1.1 oz) nylon layers were omitted). With the three-reflective systems (as in f) insulation values for these metal-on-fabric reflectives ranged from 8.45 to 8.68 clo; the much thinner, open weave NARADCOM reflective used in this system configuration produced a value of 8.66 clo. With four reflectives (as in h), values ranged from 9.39 to 9.52 clo, while the NARADCOM reflective provided 9.45 clo. It appears that insulation value was reasonably independent of the characteristics and weight of the base fabric to which the metal was bonded. All of these reflectives were reasonably permeable; however, no measurements of evaporative transfer capabilities, i.e., of Woodcock's moisture permeability index (24) were made.

Effect of reflective layers in foam insulation systems.

In a system comprising open or closed cell foams, radiant heat exchange plays only a minor role since the path lengths for radiant energy transfer are short. Therefore, reflective surfaces within a foam system should not appreciably increase insulation value. This is confirmed by the results presented in Table VII, for combinations employing two foam layers in conjunction with double-faced metallized films. With 1.3 cm (½") polyurethane foam, two reflectives increased insulation by only 0.4 clo above that using non-metallized layers (combinations c versus a); three reflectives increased insulation by only 0.5 clo (d versus b). The benefits of three reflectives were even smaller with thinner foam layers, about 0.2 clo with 0.3 cm (1/8") ensolite and 0.4 clo with 1 cm (3/8") ensolite. An additional 0.2 clo increase was obtained with the 1 cm ensolite in system e because one reflective surface was exposed; this exposed reflective reduced radiation exchange with the surroundings and, in effect, increased the insulation value of the overlying air layer.

Benefits can be produced by metallized layers in foam systems if the foam sheets have cutouts or are fabricated in some other fashion to produce open areas. This fact was demonstrated by stagger-slitting 0.3 cm (1/8") ensolite and stretching it to form a diamond pattern. Two layers opened up in this manner and employed in layering arrangment d of Table VII, (i.e., with three double-faced reflectives)

TABLE VII

REFLECTIVE FILMS WITH FOAM INSULATION

SYSTEM	(a)	(b)	(c)	(d)	(e)
37 g/m²(1.1 oz./yd.²) NYLON	—	—	—	—	
REFLECTIVE LAYER	↑	↑	↕	↕	↕
FOAM	□	□	□	□	□
REFLECTIVE LAYER	↑	↑	↕	↕	↕
FOAM	□	□	□	□	□
REFLECTIVE LAYER		↑		↕	↕
37 g/m² (1.1 oz./yd.²) NYLON	—	—	—	—	

REFLECTIVE AND FOAM TYPES	TOTAL INSULATION, clo				
½ MIL DOUBLE-FACE PVC A WITH 1.3 cm POLYURETHANE.	7.17	7.21	7.53	7.76	—
½ MIL DOUBLE-FACE PVC B WITH 0.3 cm ENSOLITE.	—	2.15	—	2.36	—
½ MIL DOUBLE-FACE PVC B WITH 1 cm ENSOLITE	—	5.64	—	6.06	6.25
½ MIL DOUBLE-FACE PVC B WITH EXPANDED (DIAMOND SHAPED) 0.3 cm ENSOLITE	—	2.66	—	5.02	—

*CLEAR PLASTIC LAYER

TABLE VIII

EFFECTS OF STITCHING BATTING SYSTEMS CONTAINING REFLECTIVE LAYERS**

	UNSTITCHED			STITCHED IN 10 cm ROWS			STITCHED IN 10 cm SQUARES		
37 g/m²(1.1 oz./yd.²) NYLON	—	—	—	—	—	—	—	—	—
REFLECTIVE LAYER	—*	⊥	⊤	—*	⊥	⊤	—*	⊥	⊤
68 g/m² POLYESTER BATT	□	□	□	□	□	□	□	□	□
REFLECTIVE LAYER	—*	⊥	⊤	—*	⊥	⊤	—*	⊥	⊤
68 g/m² POLYESTER BATT	□	□	□	□	□	□	□	□	□
REFLECTIVE LAYER	—*	⊥	⊤	—*	⊥	⊤	—*	⊥	⊤
37 g/m² (1.1 oz./yd.²) NYLON	—	—	—	—	—	—	—	—	—
TOTAL INSULATION (clo)	3.35	5.47	5.61	3.36	4.58	4.32	3.03	3.39	3.34

*CLEAR PLASTIC LAYER
**REFLECTIVES WERE ALUMINUM FOIL WITH 1.3 cm HOLES, BONDED TO GAUZE BACKING.

produced a clo value of 5.02, versus 2.66 clo with plain plastic interlayers, as in combination b. In this system, there was perhaps 70% open area and the reflectives merely blocked radiant exchange through the air spaces. This approach or a similar one using open compartments with thin foam barriers appears to have some merit, since the system can be made more resistant to compression than polyester batting systems and need not contain large amounts of foam, thus making it competitive, weightwise, with polyester battings. It is noteworthy that several U.S. companies and Russian scientists (1) are conducting studies on this type of system; i.e., one in which two reflective layers are separated by a grid of foam or felt spacing material bonded to one or both reflectives.

Effects of stitching polyester batting systems with reflective layers.

Since polyester batting is easily compressed, it was anticipated that stitching a batting system would reduce the value of reflective layers in the system. In the region of the stitches, the batting would be thinner (compressed) and more dense, reducing the potential for radiant heat transfer and thus the possible benefits from reflective layers. The results of a series of experiments on systems of 68 g/m^2 (2 oz/yd^2) staple-fiber batts combined with three layers of aluminum foil are given in Table VIII. The first three combinations were unstitched and uncompressed; these combinations were then joined together with straight rows of stitches 10 cm (4") apart; finally, the combinations were cross-stitched to form 10 cm (4") squares. As will be seen, the effects of stitching were disastrous. With no stitching, metallic layers produced increases of about 2.2 clo over the control value. With rows of stitching, the benefit with the foil layers was reduced to about 1 clo and, with the systems stitched into squares, to only about 0.3 clo; the latter is so small that it has little importance insofar as protection is concerned. Only slightly better results were obtained when the spacing between rows of stitches was increased to 15 cm (6"). It is obvious that, if reflectives are to be successfully applied in cold weather clothing, some method of joining and stabilizing the fabrics which will not compress them will have to be found. One possibility is use of physical spacers to prevent compression of the polyester batting. Some results with stiff waffle-weave spacers are given later.

Studies of compressed batting systems.

In an effort to interpret the findings with stitched systems, the effects of varying amounts of compression on reflective layer systems were studied using a single system of two 136 g/m^2 (4 oz/yd^2) batts and three bonded reflectives. The methods for applying the compressive forces and measuring thickness have been outlined previously. Results of this sequence of measurements are shown in Figure 2, a plot of insulation versus system thickness. Two curves are shown; one for a control system utilizing 204 g/m^2 (6 oz/yd^2) cotton sateen layers and the other for similar systems employing two different bonded reflectives. Both of these reflectives were of approximately the same weight and thickness as the sateen.

It is immediately apparent from Figure 2 that the insulation of the control system does not increase linearly with thickness. When it is heavily compressed (i.e., thickness less than 1.5 cm), insulation increases linearly by 1.6 clo per cm (4 clo per inch) as with conventional fabrics. However, as batting density decreases, the change with thickness becomes progressively smaller because of the increased

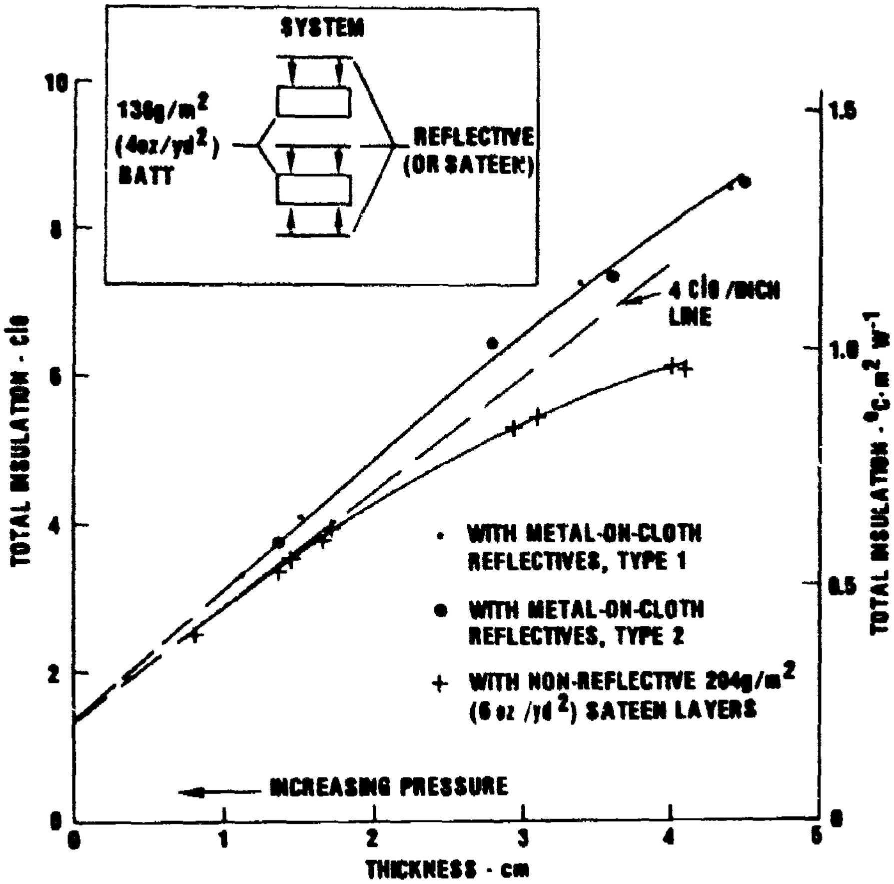


Figure 2: Loss in effectiveness of reflective layers as polyester batting systems are compressed.

contribution of radiant heat transfer. At 3 cm thickness, with the system compressed only by the weight of the hardware cloth (1.2 kg • m^{-2}), the slope of the curve falls to 0.9 clo per cm (2.3 clo per inch) and at 4 cm, uncompressed, the slope is only 0.6 clo per cm (1.5 clo per inch). The net result is that the uncompressed batting system has about 30 percent less insulating value than a comparably thick, conventional fabric system which increases insulation linearly at a 1.6 clo per cm (4 clo per inch) rate.

Figure 2 illustrates clearly that reflective layers do not import super-insulating qualities to a batting system; they primarily serve to restore the loss of insulation associated with the radiant heat exchange in less dense materials. The data points for the batting systems with reflectives essentially lie on a straight line up to about 3 cm thickness; at greater thickness and lower density, the points appear to fall slightly below this line but not nearly as dramatically as for the control system. The slope of the straight line for medium to high densities is 1.8 clo per cm (4.66 clo per inch) or 16% higher than for a conventional 1.6 clo per cm system. Thus, by reducing radiant heat loss, reflective layers might increase the insulating value of a moderately dense system by up to 16%, but no more.

The fact that the curve for the reflective systems tends to droop at the lowest densities merely indicates that not all radiation exchange is eliminated. This is partly due to failure to include a fourth, upward facing reflective between the batts, which would have reduced radiant transfer in the outer batt; however, the metallic surfaces would, even then, not completely eliminate radiant transfer since they are not perfect reflectors. In addition, they obviously cannot affect radiation exchange between fibers within a batting layer.

In Figure 2, the two curves have a common intercept of about 1.3 clo at zero thickness, which is considerably higher than the 0.5 clo value for the boundary air layer on the bare, heated flat plate. Under normal circumstances, where the fabric surface is flat, its boundary layer value is practically the same as for the bare plate, i.e., about 0.5 clo. This contribution, as noted earlier, is included in all clo values measured on the plate. The high, 1.3 clo intercept was obtained because the surface was depressed more over the test section than around the edges of the guard; this occurred because the cooling rack was undersized for the plate. This depression produced a thicker-than-normal air layer over the test section and, hence, an elevated boundary layer insulation. With reduced pressure (thicker system), the height differential would be smaller so that, with no pressure applied, the normal 0.5 clo boundary layer value should be restored. It is evident therefore that the slopes of the curves for intrinsic insulation, i.e., of the systems alone, should be greater than shown in Figure 2; i.e., the intrinsic insulation of the reflective system should vary from 0 at zero thickness (obtained by subtracting 1.3 clo), to 8.3 clo at 4.5 cm (8.8 clo total minus 0.5 clo for the boundary layer). The average slope from 0 to 4.5 cm is then 1.84 clo/cm (4.68 clo/in) instead of the 1.67 clo/cm (4.23 clo/in) derived from total insulation values.

Use of spacers to reduce compression in batting systems.

From the results in Figure 2, it is apparent why stitching reduces the effectiveness of reflectives in a polyester batting system. Compression of the batting and the increased density near the stitches reduces the potential for radiant transfer within the batting, and thus decreases possible benefits of reflective surfaces in the system. Judging from the results in Table VIII, compression from

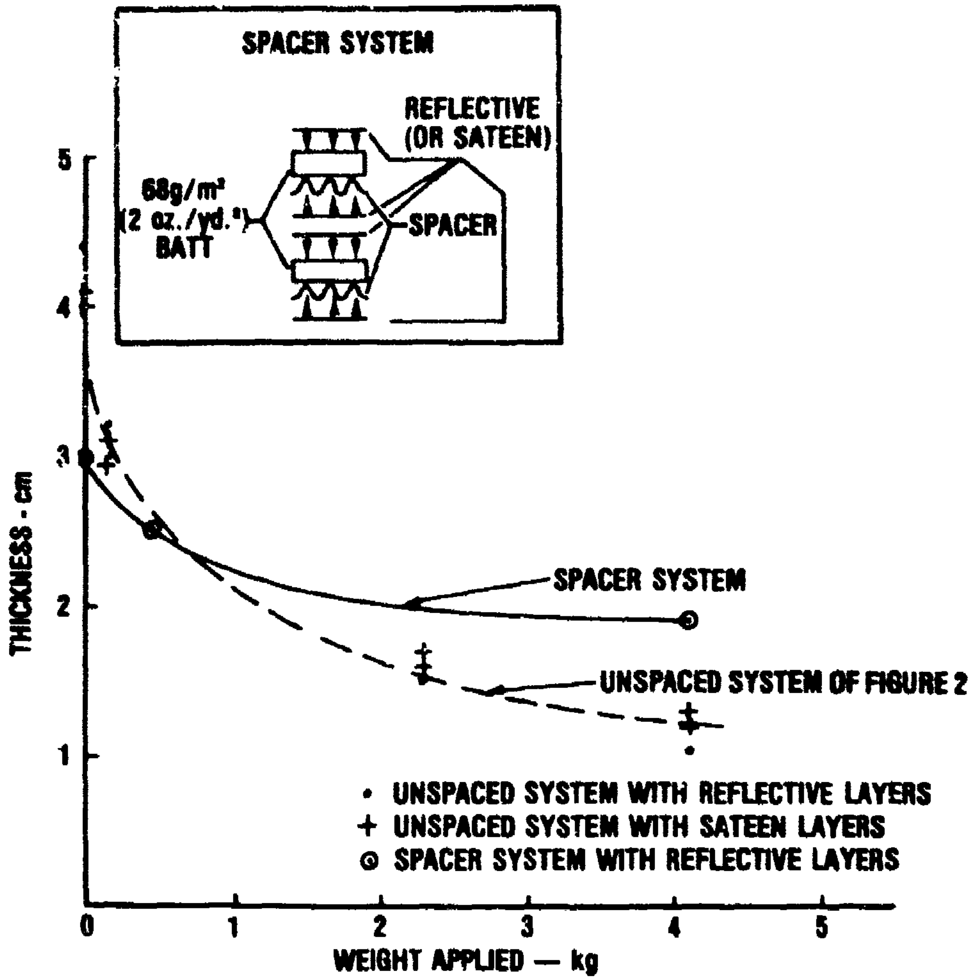


Figure 3: Thickness vs load for batting systems with and without corrugated netting spacers.

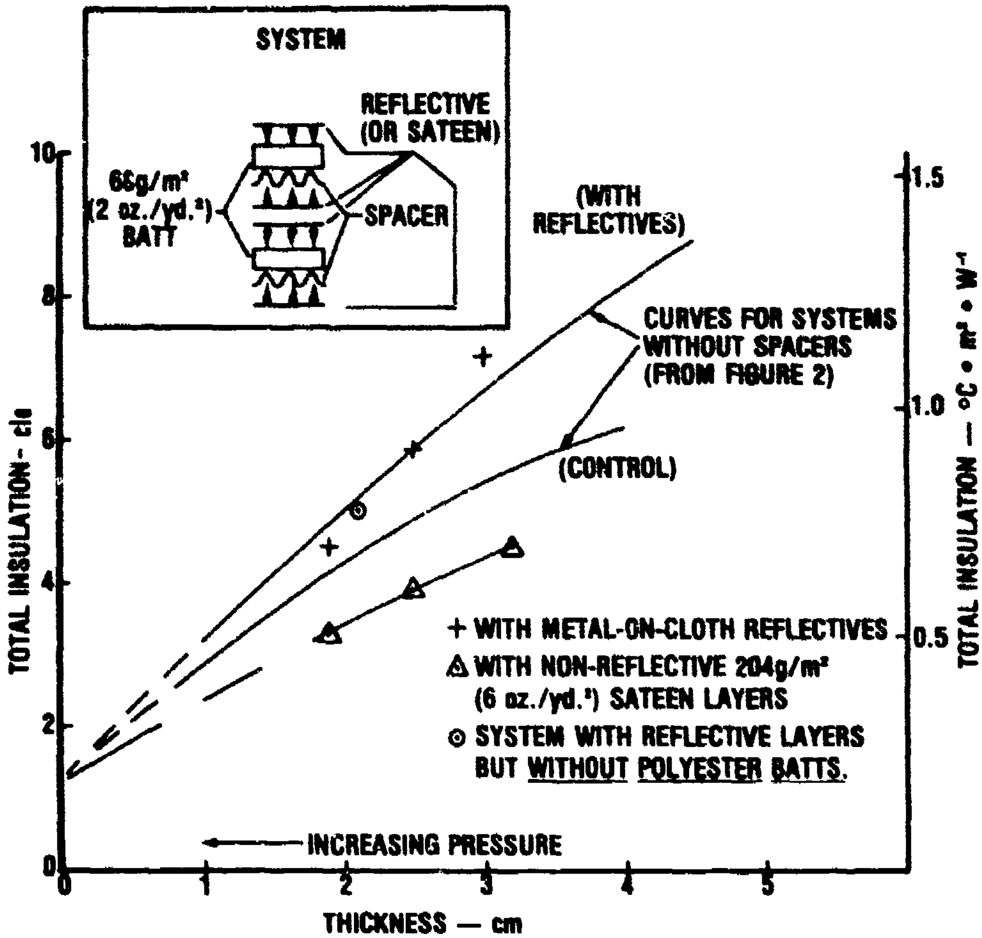


Figure 4: Effect of spacers on insulation, with and without reflective layers, of polyester batting systems under pressure.

ng extends a considerable distance, perhaps 3 to 4 cm, from the stitches; for stem stitched into 10 cm squares, reflective layers provided an increase of .3 clo (over control values), or about the same increase found when tives are used with more dense fabric layers. The compression was evident inspection of the stitched sample; essentially, stitching into 10 cm squares ided it into small "pillows" which seemed to be uncompressed only at the rs.

One method for reducing batting compression from stitching or applied t seemed promising, namely, placing a layer of stiff corrugated nylon netting, that used in air-ventilated garments (such as the EOD suit), next to each batt. spacers would restrict compression to a zone perhaps only 1 cm wide on either of any stitches. Moreover, the corrugations should aid in preventing the ng from compacting, by providing space into which the fibers could move when sure was applied. This approach for minimizing increases in batting density studied using an unstitched system of four metal-on-cloth reflectives combined h two 68 g/m^2 (2 oz/yd^2) short staple polyester batts, each next to a netting er. Figure 3 compares the thickness vs load characteristics of this system with se for the Figure 2 system without spacers. A 4.1 kg load reduced thickness th spacers by only 1.1 cm (from 3.0 cm without load to 1.9 cm), versus a 2.8 cm uction (from 4.0 to 1.2 cm) for the system with no spacers.

Insulation values for the spacer system, both with reflective layers and sateen ontrol" layers, are plotted against thickness in Figure 4; the three thicknesses, of 3.2 cm, 2.5 cm, and 1.9 cm correspond respectively to no load, 0.48 kg, and 4.1 g on the system. All points for the spacer system with reflectives, and one for the ame system but with no batting, lie near the Figure 2 line for the reflective stem without spacers; evidently, clo/cm values were not greatly affected by resence of the spacers or, in fact, by omitting the batting. However, the trend of ata points for the spacer systems seems different than the line from Figure 2; at .0 cm thickness, insulation was 0.5 clo above the line, but it was 0.3 clo below the ne at 1.9 cm. The 0.5 clo higher insulation for the spacer system at 3.0 cm uncompressed) presumably resulted from the additional reflective layer (four vs three in the system without spacers). Probably the insulation of the spacer system falls more rapidly as thickness is reduced because its batting is not as easily compressed as in the system without spacers. It is true that the latter uncompressed was 50% thicker (4.5 cm vs 3.0 cm) and, at 3.0 cm, was already compressed by one-third. However, the action of the spacers in minimizing batting compaction is a more important consideration in comparing results for the two systems. As projected earlier, applied weight simply forces the batting into the spacer corrugations without greatly compressing it. Consequently, the potential for radiation exchange remains high even when thickness is decreased. As suggested by the non-linear portion of the Figure 2 curve (with reflectives), metallized layers cannot under these conditions completely eliminate radiation exchange and the insulation value is lowered accordingly. In contrast, the batting density in the system without spacers increased rapidly with load (reduced thickness), and the reflective layers were able to block radiation almost completely at thicknesses of 2.5 cm and less; clo/cm is constant in this range, showing that radiation transfer is not a factor. As a result, the insulation of this system falls more slowly than that for the spacer system, which includes the effects of a relatively constant radiant heat loss. Thus, the advantage of the fourth reflective in the spacer system disappears below 2.5 cm thickness.

Additional evidence that the spacers minimize batting compression under load is provided by the control (i.e., with sateen layers) insulating values for the spacer system. These values are generally about 1 clo lower, at comparable thicknesses, than those for the system without spacers, indicating much higher radiant exchange. A line through the spacer system points at 2.5 and 3.2 cm has a slope of only 0.86 clo/cm (2.18 clo/inch), or about the same as for the no-spacer control system under minimal load (thickness > 3.8 cm). At 1.9 cm, (4.1 kg weight), this slope increases to only about 1.0 clo/cm (2.54 clo/inch). The change in slope is much more gradual than in the control curve for the no-spacer system, indicating that, with spacers, the dependence of radiant heat transfer on thickness is greatly reduced.

The single point in Figure 4 for a spaced reflective system without batting falls on the same line as for the system containing batting. This suggests that the batting provided the same insulation value as the empty air spaces within the corrugated spacers. This would be possible only if the batting had very low density and did not appreciably impede either convective or radiant exchange. Otherwise its insulation would have been greater than for an empty space and the total value for the system without batting would most certainly have fallen below the locus of points for the system with batting.

Even though clo/cm values under moderate to heavy loads were lower for the reflective spacer system, its overall protection characteristics were superior to those for the system without spacers. With 4.1 kg of weight, this system (1.0 cm thick) provided 3.2 clo of insulation; under the same load the spacer system was 1.9 cm thick and provided 4.5 clo, or about 40% more insulation.

Experiments were also conducted to determine whether a spacer would reduce the detrimental effects of stitching on the benefit from reflective layers. Systems comprising a layer of 68 g/m^2 batting with a corrugated spacer between either a) two metal-on-cloth reflectives or b) two sateen (control) layers, were studied unstitched and with stitched rows 10 cm apart. Insulation values were measured under no load and with 0.48 kg load.

With no load, the reflective layers increased insulation (over the control values) by 0.84 clo unstitched, and by 0.45 clo with stitched rows 10 cm apart. This 46% loss of effectiveness due to stitching was only slightly less than that for a system without spacers (cf. Table VIII-50% less benefit with stitching). With a 0.48 kg load on the spacer system, stitching reduced the benefit of the reflectives by only 34% but the system would have been compressed (by the 0.48 kg weight) even without stitching.

One should not discard the spacer concept purely on the basis of these findings. It is possible that other spacer configurations would provide more resistance to compression effects, especially if stitching tension were reduced or alternate methods of joining the fabrics were employed. However, if spacers are employed, attention must be paid to their effect on total thickness, since too much bulk is unacceptable. The single spacer system used to study the effects of stitching was entirely too thick as a liner in the standard Arctic trousers or parka, and badly stretched the garment shells; possibly because of this mismatch, insulation of an Arctic ensemble employing reflective liners of this design was no higher than with the conventional polyester batting liners, which employ no reflectives or spacers.

Results for actual clothing systems and other individual protection items.

A number of Arctic parka and trouser liners, sleeping bags, and cold weather handwear and footwear items incorporating reflective layers were fabricated for evaluation on other physical devices such as the copper manikin, or a sectional copper hand or foot. In these actual clothing items, the reflectives were located in positions and orientations which, according to the flat plate results, would have the greatest promise for improving insulation.

a. Reflectives in Arctic parka and trouser liners.

The initial study involved a comparison of the insulation values of the standard A Arctic uniform, which included M-65 Arctic Trouser and Parka polyester batting liners, with that of the same ensemble but with reflective films included in the liners. The liners were layered as in system k, Table II. Total insulation for this ensemble was 4.58 clo, only 5.7% greater than the 4.33 clo value measured on the standard A ensemble with no reflectives. In subsequent studies, insulation increase was determined with (a) two reflective films facing a 136 g/m^2 (4 oz/yd^2) continuous filament polyester batt in the Arctic parka and trouser liners, (b) two reflective films facing a 204 g/m^2 (6 oz/yd^2) continuous filament polyester batt in the field jacket and trouser liners, and (c) the same arrangement and placement as in (b) except that the liners were made up of alternating 10 cm (4") squares with and without reflective films (i.e., in a checkerboard pattern); this arrangement was employed to improve the evaporative heat transfer characteristics of the ensemble, which were unsatisfactory with continuous reflective films (impermeable) in the liners. The ensembles in (b) and (c) did not include Arctic parka or trousers, or their liners. Results were as follows:

Liner System	Liner Location	Insulation Value (Clo)
37 g/m^2 ripstop covers plus:		
(a) Reflectives $\bar{c}$ 136g/m^2batt	Arctic parka and trousers	4.89
136 g/m^2 batt (control)	Arctic parka and trousers	4.40
Increase with reflectives = 11%		
(b) Reflectives $\bar{c}$ 204g/m^2batt	Field jacket and trousers	3.50
204 g/m^2 batt (control)	Field jacket and trousers	3.35
Increase with reflectives = 4.2%		
(c) 50% Reflectives $\bar{c}$ 204g/m^2batt	Field jacket and trousers	3.49
204 g/m^2 batt (control)	Field jacket and trousers	3.35
Increase with reflectives = 4.2%		

For some unexplained reason, the insulation value with alternating squares of reflective film (only 50% area coverage) was the same as when the films were continuous. Theoretically, the higher radiation transfer across those batting sites which had no reflective films should have lowered insulation value. More importantly, the use of alternating squares of film increased potential for

evaporative heat loss to 2.4 times that for the ensemble with continuous film liners (system b).

One final experiment, in which two metal-on-fabric reflectives facing a 136 g/m^2 batt and a corrugated net spacer were used as liners for the Arctic parka and trousers, failed to show any real benefit of a spacer. To compensate for the extreme bulkiness of these liners, the field jacket and trousers and their liners were omitted from the ensemble; the outer garments otherwise would have been severely compressed. Total insulation was 3.94 clo with the reflectives in the liners versus 3.89 clo when plain cloth was substituted for the reflectives. This barely detectable difference is of no practical importance.

b. Reflective layers in sleeping systems.

Only limited data were collected to suggest effects of radiation barriers on insulation of sleeping systems. In one such evaluation, a standard mountain bag was encased in a blanket made from a reflective with polyester fibers pulled through a multiplicity of needle punched holes in a metal layer to form a layer 3.2 mm (1/8") thick. The insulating value, measured with the system on a standard inflatable pad was 5.80 clo, versus 5.69 clo with the bag encased in a standard poncho blanket. This benefit of the reflective layer, i.e., 0.11 clo, is obviously not an adequate return for the increased complexity of the reflective-type blanket.

c. Reflective layers in handwear items.

The extensive stitching required in fabricating a mitten or glove liner, plus the unavoidable batting compression which occurs around the finger tips with a mitten, and between fingers with a glove, suggested there would be only limited benefit from reflectives incorporated in a handwear system. Several evaluations of new, and used, Arctic mitten systems consisting of a wool mitten, polyester batting liner, and an Arctic shell on the sectional copper hand confirmed this prediction. In general, reflective films in the polyester liner increased overall hand protection by from 3 to 10% for new mitten systems (from 1.80 to 1.92 clo on the average); this percentage increase was reasonably consistent over the hand surface. However, the insulation over the finger tips, the most critical area, was increased by the reflectives from 1.57 clo to 1.72 clo, on average. The increase in this area is impressive and may have physiological significance insofar as hand protection is concerned. After field use, these mittens all showed a decrease of about 0.2 clo in overall insulation due to compression and shifting of the polyester batting in the liners. The reflective films also separated wherever they were stitched, but this did not cause a pronounced loss (less than 0.2 clo) in overall insulation effectiveness. The average insulation over the fingertips in the used systems was raised from 1.45 to 1.56 clo, or about 8%, by the reflectives. Further investigation of reflectives in extreme-cold handwear seems justified, particularly in view of an initial evaluation of the use of reflectives in combination with auxiliary heating systems which showed some improvement in efficiency of applied heat when reflective layers were included.

d. Reflectives in footwear.

Use of reflectives in conventional footwear is generally not indicated

since low density battings and fabrics are normally not employed; more dense materials are required to provide foot stability while walking. One application with considerable promise, however, is in a lightweight polyester batting bootee for providing supplementary foot insulation while sleeping in the cold. Such an item could be of simple construction, and easily stored during the day. More importantly, our measurements of three versions of these boots indicate that, even without reflectives, they provided more insulation overall than either the standard cold-wet or cold-dry insulated boot; this is made possible by their simple, uncompressed construction. The versions studied on the sectional copper foot had a layering arrangement like that in (k), Table II, i.e., with 37 g/m^2 nylon faces, two 68 g/m^2 batts, and three reflective films. One version had, in addition, a nylon oxford cover and thin canvas sole, a second had the sole but no cover, and a third had a glove leather sole and oxford cover. The reflectives increased overall insulation by from 7% to 25% (0.2 to 0.5 clo), compared with control bootees without any films; compression of the batting when attaching the leather sole (bootee #3) was responsible for the lowest (7%) increase. The best bootee, version #1, had an overall insulation, with reflectives, of 2.3 clo, compared with 1.7 clo for the standard cold-dry vapor barrier boot. In this version, the toe cap insulation was 1.65 clo, versus 1.85 clo for the cold dry boot, but most of the other foot areas were better protected in the bootee than in the vapor barrier boot. These items appear to have promise as tent socks or could significantly extend the comfort range of a cold weather sleeping system with minimal weight increase.

ACKNOWLEDGEMENTS

Mr. Harold E. Hanson was responsible for most of the measurements and many of the system designs in the early phases of the flat plate study. His meticulous work and attention to detail were essential to the success of this project.

Messrs. O. F. Compagnone and C. A. Levell, of the Military Ergonomics Division performed the measurements on clothing items and ensembles. Mr. T. L. Endrusick continued the flat plate work after Mr. Hanson's retirement. The contributions of these individuals are gratefully acknowledged.

Special thanks is due Mr. Herman Madnick and other USANARADCOM personnel who furnished the experimental fabrics, batting, and reflective materials and fabricated various systems into clothing items for evaluation.

REFERENCES

1. Afanas'yeva, R.F. and Gorshkova, R. I. Hygienic evaluation of the thermal insulating properties of clothing made of fabrics with high reflecting properties (English Title). Gigiyena i Sanitariya, No. 6: pp. 43-47, 1973.

2. Breckenridge, J. R. Fiberglas lining in cold weather garments. Climatic Research Laboratory Rept. No. 121, Military Planning Division, Office of the Quartermaster General, Washington, DC, June, 1947.

3. Burton, A.C. Insulation by reflection and the development of a reflecting cloth. S.P.C. Rept. No. 116, Assoc. Comm. on Aviation Med. Res., Nat. Res. Counc., Canada, April, 1943.

4. Burton, A.C. and Edholm. O.G. Man in a Cold Environment, pp. 54-55. Facsimile of 1955 Edition, Hafner, New York, 1969.

5. ibid, pp. 62-63.

6. Carli, B. Reflectivity of metallic films in the infrared. J. Opt. Soc. Am., 67:908-910, 1977.

7. Cleveland, R.S. An improved apparatus for measuring the thermal transmission of textiles. J. Res. Nat. Bur. Standards 19:675, 1937.

8. Dee, T.E., Jr. Evaluation of aluminized fabrics. Climatic Research Laboratory EPS Test Rept. No. 5026, Office of the Quartermaster General, Washington, DC, December, 1950.

9. Fourt, L. and Harris, M. Chapter 10: Physical properties of clothing fabrics, pp. 302-304. In: Physiology of Heat Regulation and the Science of Clothing, L.H. Newburgh, Ed., Facsimile of 1949 Edition, Hafner, New York, 1968.

10. ibid, pp. 294-298.

11. Fourt, L. and Hollies, N.R.S. Clothing Comfort and Function, pp. 31-37. Dekker, New York, 1970.

12. ibid, pp. 84-86.

13. Gagge, A.P., Burton, A.C., and Bazett, H.C. A practical system of units for the description of the heat exchange of man with his environment. Science 94:428-430, 1941.

14. Goddard, W.L. and VanDilla, M. Air layers; thermal properties when bounded by surfaces of high and low emissivity. Climatic Research Laboratory Rept. No. 80, Military Planning Division, Office of the Quartermaster General, Washington, DC, December, 1945.

15. Goldman, R.F. Systematic evaluation of thermal aspects of air crew protective systems. In: Behavioral Problems in Aerospace Medicine, Conference Proceedings No. 25 of the Advisory Group for Aerospace Research and Development, Paris, October 1967.

16. Goldman, R.F. Clothing design for comfort and work performance in extreme thermal environments. Transactions of the New York Academy of Sciences, 36:531-544, 1974.

17. Hardy, J.D. Chapter 3: Heat transfer, pp. 79-84. In: Physiology of Heat Regulation and the Science of Clothing, L.H. Newburgh, Ed., Facsimile of 1949 Edition, Hafner, New York, 1968.

18. Holman, J.P. Heat Transfer, pp. 187-206. McGraw Hill, New York, 1968.

19. ibid, pp. 212-220.

20. ibid, pp. 238-241.

21. Morris, R.O. The development of the testing techniques and procedures utilized at the Climatic Research Laboratory. Climatic Research Laboratory, Military Planning Division, Office of the Quartermaster General, Washington, DC, May 1946.

22. Pratt, R.L. Effect of solar heat. Env. Prot. Br. Rept. No. 185, Office of the Quartermaster General, Washington, DC, 1950.

23. Rapp, G.M. Convection heat transfer and convection coefficients of nude man, cylinders and spheres at low air velocities. ASHRAE Transactions 79:(part I), 1973.

24. Woodcock, A.H. Moisture transfer in textile systems, Part I. Text. Res. J., 32:628-633, 1962.

DISTRIBUTION LIST

5 copies to:

US Army Medical Research and Development Command
Fort Detrick
Frederick, MD 21701

12 copies to:

Defense Documentation Center
ATTN: DDC-TCA
Alexandria, VA 22314

1 copy to:

Superintendent
Academy of Health Sciences, US Army
ATTN: AHS-COM
Fort Sam Houston, TX 78234

1 copy to:

Dir of Biol & Med Sciences Div
Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217

1 copy to:

CO, Naval Medical R&D Command
National Naval Medical Center
Bethesda, MD 20014

1 copy to:

Dir of Prof Svcs
Office of The Surgeon General
Department of the Air Force
Washington, DC 20314

1 copy to:

Director of Defense Research and Engineering
ATTN: Assistant Director (Environmental and Life Sciences)
Washington, DC 20301